# Breakthrough Technologies to Find and Image Oil Deposits

*We are developing technologies to help the U.S. oil industry find and recover more oil from existing fields.*

We are drawing upon LLNL expertise in physics, computational modeling, and groundwater remediation to develop three different technologies for the DeepLook consortium, an oil industry collaboration that was formed to find breakthrough technologies for detecting, predicting, and monitoring hydrocarbons. The goal is to develop more accurate and economical tools that will enable the industry to recover a larger proportion of the oil or gas in a given field.

Livermore's three projects are:

- A novel computational physics approach that combines "forward" and "inverse" modeling with signal-processing techniques to produce images of fluid and rock properties from wellbore measurements.
- The use of artificial neural networks and genetic algorithms—another approach to modeling—to quickly assess possible scenarios for developing an oil or gas field.
- An innovative approach to nuclear magnetic resonance imaging that uses the earth's magnetic field.

The industry, as the DeepLook name implies, wants to be able to "see" oil that lies in reservoirs deep below the surface and at a distance from existing wells. In a typical field, less than one-third of the existing oil is recovered or produced; more than two-thirds of the oil resources available in the rock formations is bypassed. Pressures in the reservoir drive some of the oil toward the wellbores that penetrate these rock formations, but these pressures are inadequate to move much of the oil toward the wellbores. Secondary production techniques to enhance oil recovery involve injecting fluids into various points of the reservoir to "sweep" more of the oil toward the wellbores.

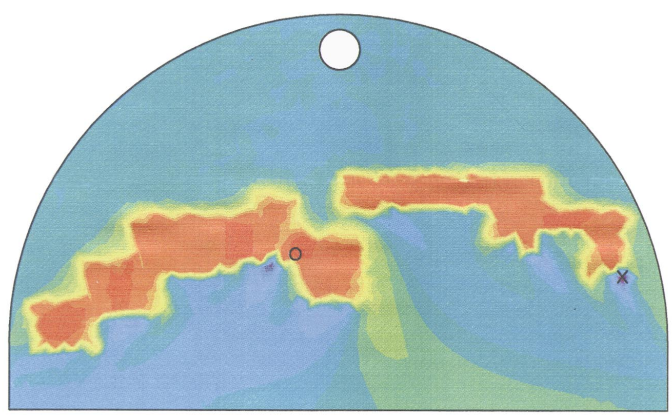
The DeepLook collaboration hopes to find technologies that will work together to provide more accurate images and information about this unswept oil and then to make these technologies available commercially.

## Forward-Inverse Modeling to Look at Permeability Regions

We are developing computational modeling techniques to improve images in reservoir regions of varying permeability and to identify the most productive locations and pathways for injecting water to sweep out more oil at less cost.

These techniques solve a "forward" flow model that interpolates available pressure data concurrently with solving an "inverse" model, which derives permeability from available rock data and forward-model-generated pressure gradients—by solving partial differential equations accurately with "adaptive grid" methods. "Signal-processing" equations have been combined with these models to both suppress noise and gain the best image resolution that is consistent with information science for sparsely sampled data.

We have achieved proof-of-concept in verifications of 2-D example problems derived from petroleum engineering, with reservoir properties that resemble the Pompano deepwater field in the Gulf of Mexico. High-quality images from sufficiently dense pressure data (thousands of data points) have demonstrated the substantial resolving power of these techniques. Preliminary results obtained from sparse pressure data (1–75 wells) are also encouraging. We are now refining



This 2-D image was produced by forward-inverse modeling. The red and orange areas denote the least permeable regions within this oil dome—barriers to the flow of oil. The round white "hole" at the top of the image represents the wellbore.

these techniques to include more realistic physics and to assess the nature of image distortions between wellbores with sparse data sets that are typical of practical wellfields. The eventual goal, an even more complex problem, is to develop the modeling techniques to produce good 3-D images.

## Neural Networks Methods to Evaluate Field Development Scenarios

Neural networks, computational methods that derive their name from their similarity to networks in the human brain, are adept at pattern recognition, classification, and estimating numbers in poorly understood situations. We are extending techniques originally developed to evaluate strategies for remediating contaminated groundwater to the problem of locating the best possible water flood strategy to maximize gas and oil production in the Pompano field.

In this work, neural networks are trained to predict how oil and gas production will be affected by development strategies, which in this case consist of different combinations of prospective water injection sites spread throughout the field. Networks are trained from a few carefully selected examples created by running a large, time-consuming numerical model of the field. The trained networks then “fill in the gaps” so that hundreds of different combinations of injection sites can be quickly evaluated. The networks evaluate each development strategy in fractions of a second, rather than the hours required by the numerical model.

The networks only predict the influence of the injection wells on production figures. Searching for better and better combinations of wells, out of the huge number of possibilities, is handled by a second computational technique: the genetic algorithm. This technique creates new, improved strategies by “mating” older strategies that have proven to be relatively successful, in somewhat the same way that breeders improve livestock by mating animals with desirable characteristics to get even better off-spring.

Our work to date has shown that a 15% improvement in expected net profit for the field over the next seven years can be obtained by a simple application of these techniques. Our next focus is on extending the time-frame over which we make planning predictions and incorporating more knowledge specific to the oil industry into our calculations.

## Nuclear Magnetic Resonance to Detect Hydrocarbons

Nuclear magnetic resonance is based upon the fact that an atom will oscillate when subjected to electromagnetic waves of a given frequency in conjunction with a constant magnetic field. When the electromagnetic waves cease, the atoms will spin or flip back to their original orientation while emitting a detectable “echo” of the same frequency.

The oil industry currently applies NMR in oil wells by injecting a high-strength magnetic field and using high-frequency electromagnetic waves. However, these high-frequency electromagnetic waves penetrate only a few inches beyond the borehole.

Instead of modulating a strong magnetic field, our technology modulates the earth’s own magnetic field, which is very weak and thus enables us to use low-frequency signals that can penetrate the earth for hundreds of meters. We tune the signal for hydrogen atoms, which occur in both hydrocarbons and water, but the atoms in oil flip much more quickly than those in water—one-hundredth of a second compared to a tenth of a second. By working at a certain depth within a borehole and then detecting the timing and location of the return signals, we can determine if there is oil present and how far it is from the borehole. Triangulating this data from multiple boreholes will determine the oil’s location.

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